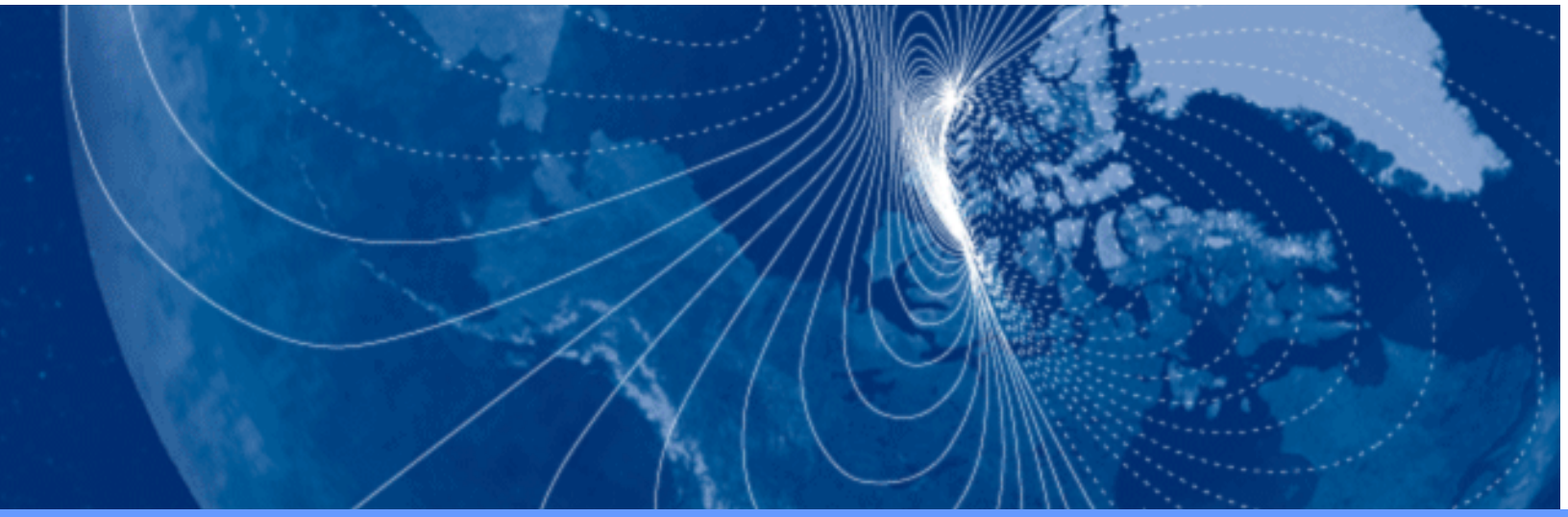

User Manual

MagIC™

SmartSens High Data Rate Sensor Controller

PNI
SENSOR CORPORATION

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1 Copyright & Warranty Information

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2 Introduction

Thank you for purchasing PNI Sensor Corporation's SmartSens MagIC™ ASIC (PNI part number 12739). The MagIC is a high-data-rate controller ASIC for use with PNI's SmartSens magneto-inductive (MI) sensors (the Sen-XY™ and Sen-Z™). It contains drive and measurement circuitry for interaction with SmartSens sensors, interface circuitry to communicate with a host microprocessor on an SPI bus, an internal clock and inputs for a user-supplied external clock or crystal oscillator. The MagIC can control and measure three independent SmartSens sensors. Each SmartSens sensor is individually selectable for measurement, and can be individually configured for measurement resolution

PNI's SmartSens product line also includes the 11096 ASIC, MS2100™ single-chip solution, and the MicroMag family (MicroMag2™, MicroMag3™, and MicroMagIC™). The main differences between the MagIC and 11096 ASIC are the data rates and footprint, with the 11096 ASIC having a smaller footprint and the MagIC providing higher data rates. PNI's MS2100 IC is a single IC solution incorporating two SmartSens MI sensors and an 11096 ASIC, while PNI's MicroMag modules contain 2 or 3 SmartSens sensors and either the 11096 ASIC or MagIC.

For most applications the SmartSens MI sensor serves as the inductive element in a simple LR relaxation oscillation circuit, with its effective inductance proportional to the magnetic field parallel to the sensor axis. When driven by the MagIC, the frequency of oscillation varies with the strength of the magnetic field parallel to the sensor.

The output from the MagIC is inherently digital and can be fed directly into a microprocessor, which eliminates the need for signal conditioning or an analog/digital interface between the sensor and a microprocessor. The simplicity of the SmartSens circuit combined with the lack of signal conditioning makes it easier and less expensive to implement than alternative fluxgate or magneto-resistive (MR) technologies.

Since the SmartSens circuit works in the frequency domain, resolution and noise are established cleanly by the number of period counts. In comparison, fluxgate and MR technologies require expensive and complex signal processing to obtain similar resolution and noise, and for certain applications the SmartSens solution cannot be matched.

The user may wish to refer to PNI's MicroMagIC User Manual to provide aid in the evaluation and prototyping of the MagIC module.

3 Specifications

Table 3-1: Absolute Maximum Ratings

Parameter	Symbol	Maximum
DC Supply Voltage for I/O	VCCIO	3.75 VDC
DC Supply Voltage for Core	VCC	1.65 VDC
Digital Input Voltage	V_{IN}	-0.3V to 3.6V

CAUTION:

Stresses beyond those listed Table 3-1 may cause permanent damage to the device. These are stress ratings only. Functional operation of the device at these or any other conditions beyond those indicated in the operational sections of the specifications is not implied. Exposure to absolute maximum rating conditions for extended periods may affect device reliability.

Table 3-2: Recommended Operating Conditions

Parameter		Symbol	Min	Typ	Max	Unit
Supply Voltage	for I/O	VCCIO	2.7	3.0 or 3.3	3.6	VDC
	for Core	VCC	1.425	1.5	1.575	VDC
Bias Resistance	VCCIO = 3.0 V	Rb		53		Ω
	VCCIO = 3.3 V	Rb		62		Ω
Operating Current[1] measured at VCC	PS = 32, 80 Hz			1.7		mA rms
	PS = 1024, 37 Hz			3.6		mA rms
Idle Mode Supply Current				55		µA
Digital Output	External load capacitance at each output pin to ground.	C_L		5		pF
	High level output voltage	V_{OH}	2.4	VCCIO		V
	Low level output voltage	V_{OL}		0	0.4	V
Digital Input	Input Capacitance	C_{IN}			8	pF
	High level input voltage	V_{IH}	2		3.6	V
	Low level input voltage	V_{IL}	-0.3		0.8	V
	High level input current	I_{IH}		10		µA
	Low level input current	I_{IL}		10		uA
Temperature	Operating		-40		+85	C
	Storage		-65		+150	C

Note:

1) "PS" is the "period select", which is set by the user in software, and is inversely proportional to the data rate, as show in Figure 4-1. Minimum PS = 8 and Maximum PS = 4095. The listed data rate is per axis.

Table 3-3: Timing Requirements

Parameter	Min	Typ	Max	Unit
Clock frequency		1		MHz
Pulse duration low	$0.45*t_{SCLK}$			ns
Pulse duration high	$0.45*t_{SCLK}$			ns

4 Typical Operating Characteristics

Note that “Period Select” is set by the user in software.

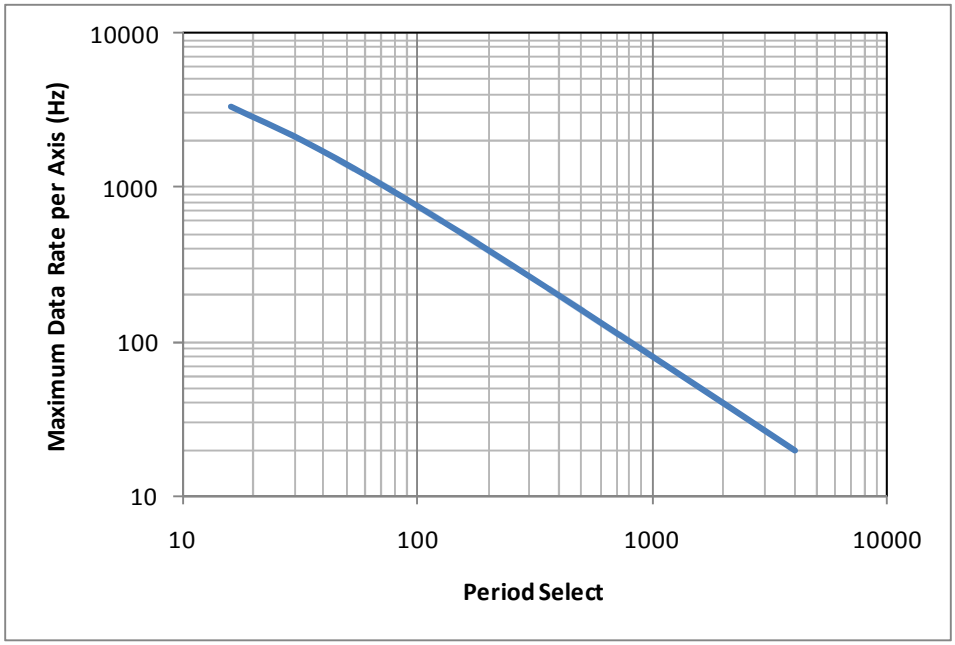

Figure 4-1: Maximum Data Rate per Axis vs. Period Select

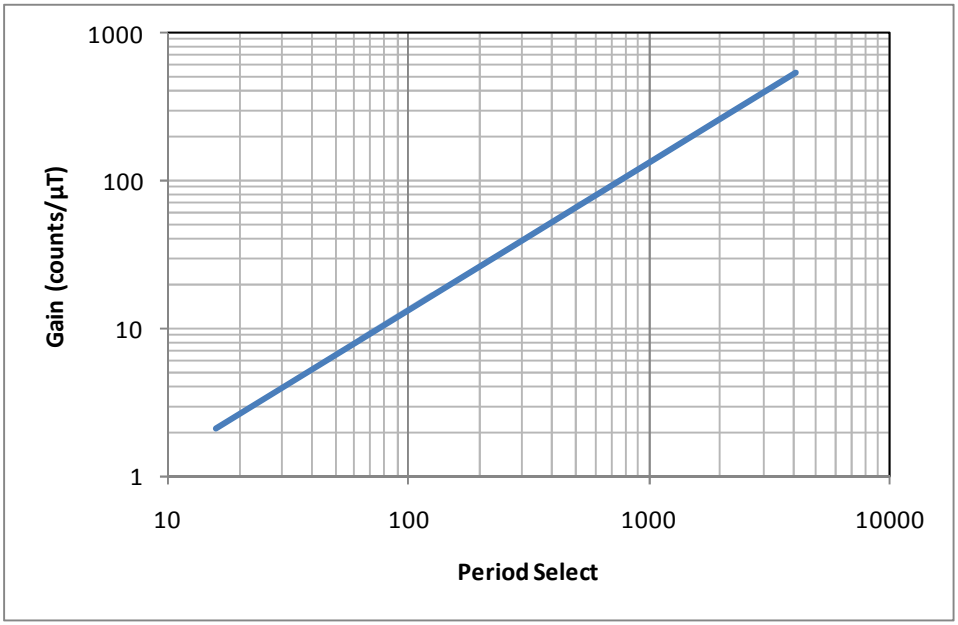

Figure 4-2: Gain vs. Period Select
(Resolution = 1/Gain, to the system’s noise limit)

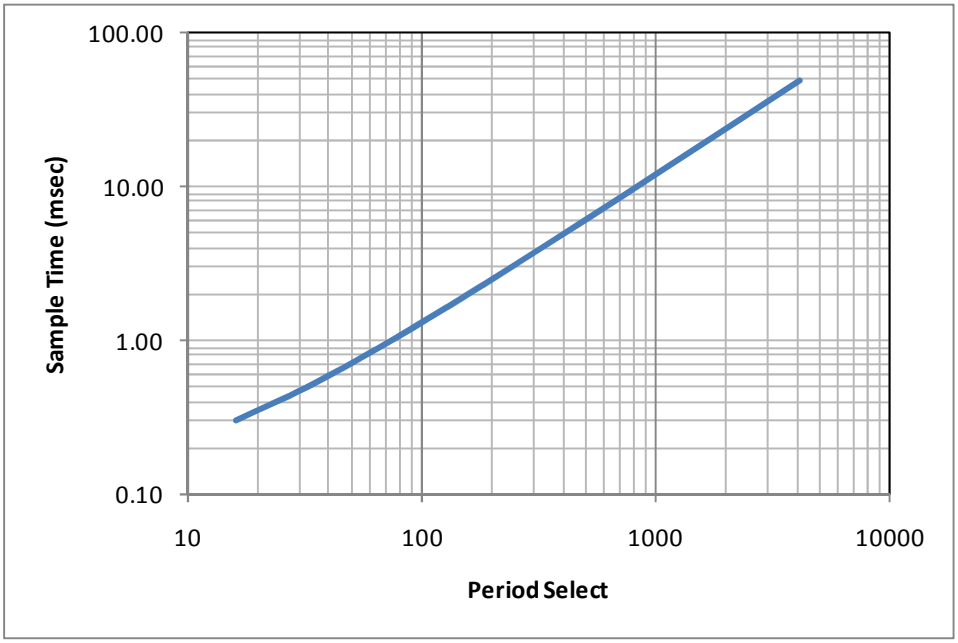

Figure 4-3: Sample Time per Axis vs. Period Select

5 Dimensions and Packaging

Dimensions in mm.

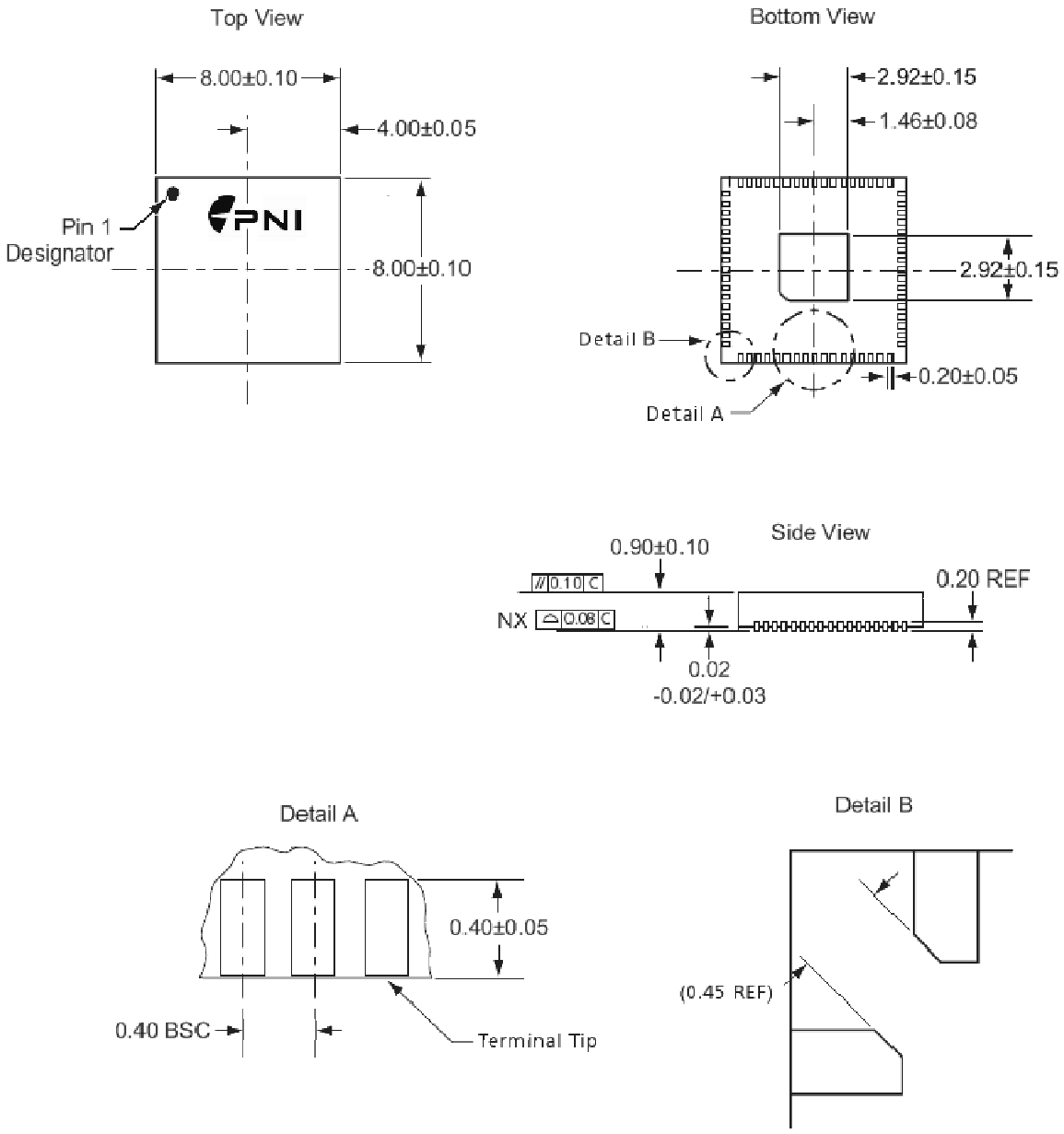

Figure 5-1: MagIC Mechanical Drawing

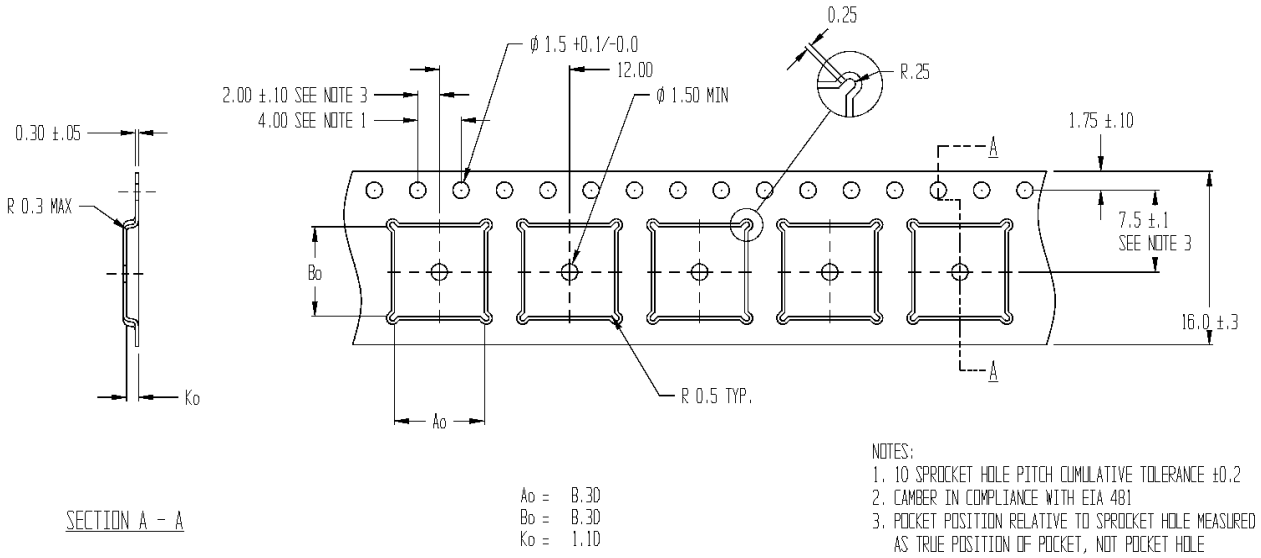

Figure 5-2: MagIC Tape Dimensions

6 Overview and Set-Up

6.1 Overview

The MagIC ASIC is intended as a component in a SmartSens magnetic measurement circuit, as show in Figure 6-1, with a detail of how the biasing works in Figure 6-2.

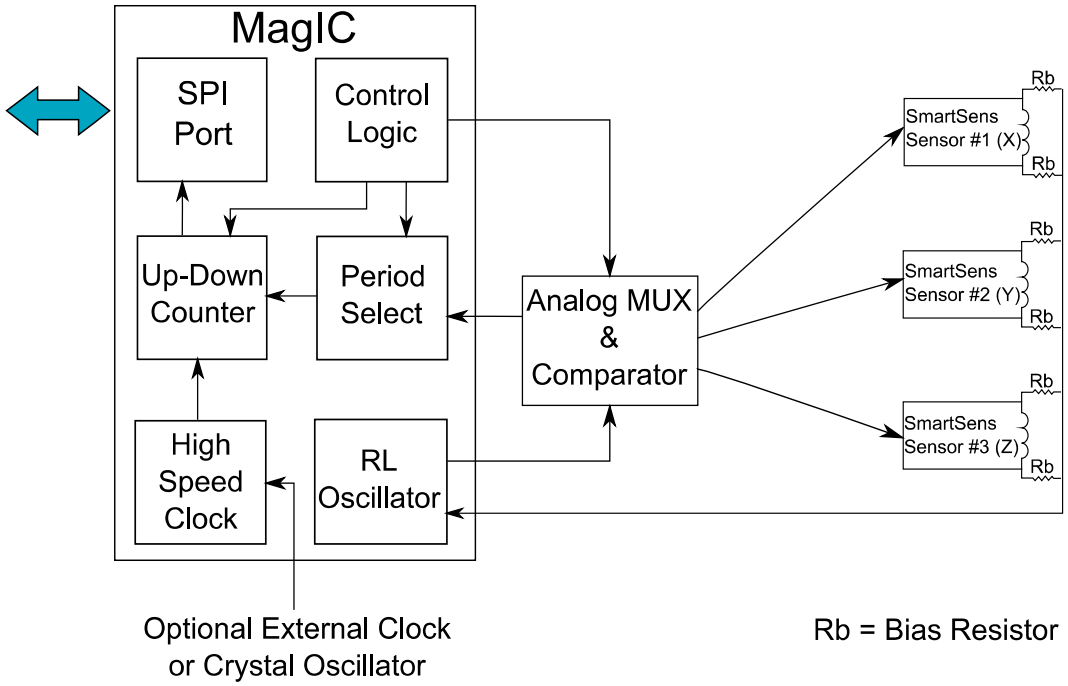

Figure 6-1: MagIC and SmartSens Circuit Block Diagram

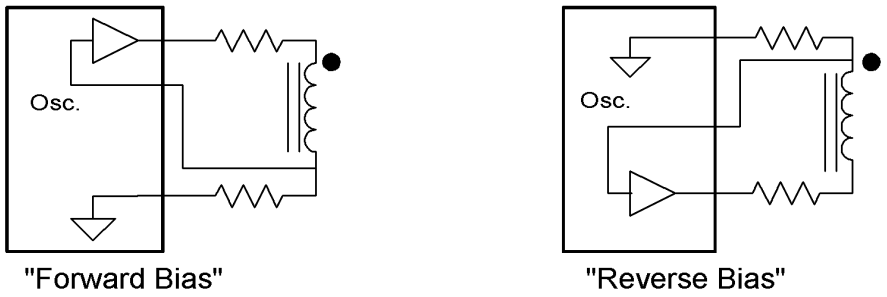

Figure 6-2: Biasing Diagram

The MagIC's output reading provides the difference in the high-speed oscillator period counts between forward-biased and reverse-biased sensor measurements. To make a measurement, one side of the sensor is grounded while the other side is alternately driven with positive and negative current through the oscillator. The Period Select is user-defined in software and establishes how many oscillations of the RL circuit are desired per measurement. The greater the Period Select, the higher the resolution of the measurement and the longer the sample time. The high-speed oscillator measures how long it takes to make the desired number of RL circuit oscillations. The MagIC will then switch the bias connection to the sensor and make another measurement. The side that was previously grounded is now charged and discharged while the other is now grounded. The MagIC can be used to interface from one to three sensors depending on application requirements: ***unused sensor connections should remain floating***. The MagIC contains drive and measurement circuitry for interaction with PNI's SmartSens magneto-inductive sensors, interface circuitry to communicate with a host microprocessor on an SPI bus, an internal clock and inputs for an optional external clock or crystal oscillator

6.2 MagIC Pinout and Connections

The MagIC's pinout is summarized in Table 6-1. The pinout runs counterclockwise on the MagIC (when looking from the top), starting at the Pin 1 designator as shown in Figure 5-1.

As indicated in Figure 6-1, implementation of the MagIC requires incorporation of a user-supplied analog multiplexer and comparator. Figure 6-3 (below) provides reference circuit information for incorporating a Texas Instruments 74HC4051 analog multiplexer and Texas Instruments LMV761 comparator.

Table 6-1: MagIC Pinout

Pin#	Pin Name	Description
1	MUXA0	Analog MUX Channel Select Address Output
2	MUXA1	Analog MUX Channel Select Address Output
3	MUXA2	Analog MUX Channel Select Address Output
8,24,46,61	VCC	1.5V Supply for Core
9,25,45,60	GND	Ground Pins
10,26,44,59	VCCIO	3.3V Supply For I/O
12	MGSW_SD	Shutdown Signal Output To Analog MUX
14	~YDRV	Y Sensor Negative Drive Signal Output
16	YDRV	Y Sensor Positive Drive Signal Output
17	XDRV	X Sensor Positive Drive Signal Output
18	~SLEEPMODE	Disabled
20	~XDRV	X Sensor Negative Drive Signal Output
22	~ZDRV	Z Sensor Negative Drive Signal Output
23	ZDRV	Z Sensor Positive Drive Signal Output
27	SSNOT	SPI Slave Select (Negative True)
28	DRDY	Data Ready Output
32,33,34,36,37	TEST	Do not connect
35	TSTP	Pin should be tied to ground
38	TSTJ	Pin should be tied to ground
39	MOSI	SPI Serial Data Out (Master Out Slave In)
40	MISO	SPI Serial Data Out (Master In Slave Out)
41	SCLK	SPI Serial Clock Input
42	CLK_IN	External Clock Input
43	RESET	Reset Input
47	CLK_OUT	High-Speed Clock Output
48	CLK_DIV	Internal Clock Speed (LOW=High-Speed, HIGH=High-Speed/2)
49	INT_EXT_CLK	Clock Select Input (LOW=Internal, HIGH=External)
50	CLK_OUT_ENBL	High-Speed Clock Enable Output (HIGH=Enable)
67	MAG_OUT	Mag Oscillator Output (a MagIC Input)
68	~MAG_SD	Negative Shutdown Signals to Peripherals (Output)
4,5,6,7,11,13,15,19,21, 29, 30,31,51–58,62-66	NC	No Connection

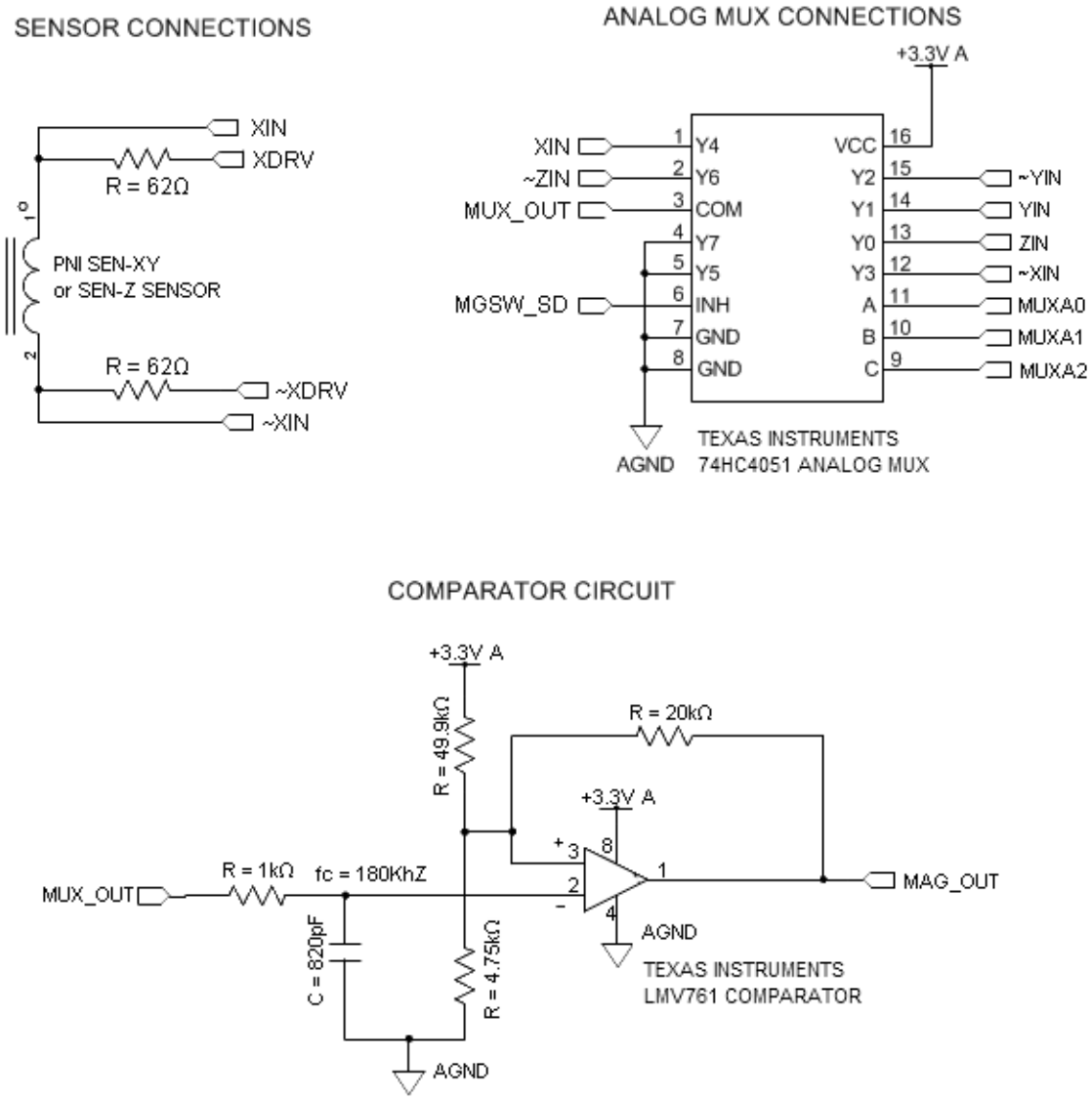

Figure 6-3: Reference Sensor & Analog Mux Connections and Comparator Circuit

6.2.1 SPI Port Lines

SCLK (SPI Serial Clock Input)

An SPI input is used to synchronize the data sent in and out through the MISO and MOSI lines. SCLK is generated by the customer-supplied master device and should be 1 MHz or less. One byte of data is exchanged over eight clock cycles. Data is captured by the master device on the rising edge of SCLK. Data is shifted out and presented to the MagIC on the MOSI pin on the falling edge of SCLK.

SSNOT (SPI Slave Select)

This signal sets the MagIC as the operating slave device on the SPI bus. The SSNOT line must be LOW prior to data transfer in either direction, and must stay LOW during the entire transfer. The SPI bus can be freed up (SSNOT line set HIGH) for communication with another slave device while the MagIC is taking a measurement or idle, but after all communication between the MagIC and master device is finished.

MISO (SPI Serial Out)

An SPI output that sends data from the MagIC to the master device. Data is transferred most significant bit first and is captured by the master device on the rising edge of SCLK. The MISO line is placed in a high impedance state if the MagIC is not selected as the slave (SSNOT=1).

MOSI (SPI Serial In)

An SPI input that provides data from the master device to the MagIC. Data is transferred most significant bit first. Data must be presented at least 100 ns before the rising edge of SCLK, and remain valid for 100 ns after the edge. New data may be presented to the MOSI pin on the falling edge of SCLK.

6.2.2 Hardware Handshaking Lines

RESET (Reset)

RESET must be toggled LOW-HIGH-LOW before sending a measurement command. RESET is usually LOW.

DRDY (Data Ready)

It is recommended the DRDY line be used to ensure data is clocked out of the MagIC only when it is available. DRDY is set low after a RESET. After a command has been received and the data is ready, DRDY will be changed to high.

6.3 Clock Options

The MagIC can be configured for various high-speed clock options, including selection of: internal or external clock (INT_EXT_CLK, pin 49), outputting or not outputting the clock (CLK_OUT_ENBL, pin 50), and dividing the clock rate by 2 (CLK_DIV, pin 48). ***Pins 48, 49, and 50 should not be left floating: rather they should be either tied to ground or VCC.***

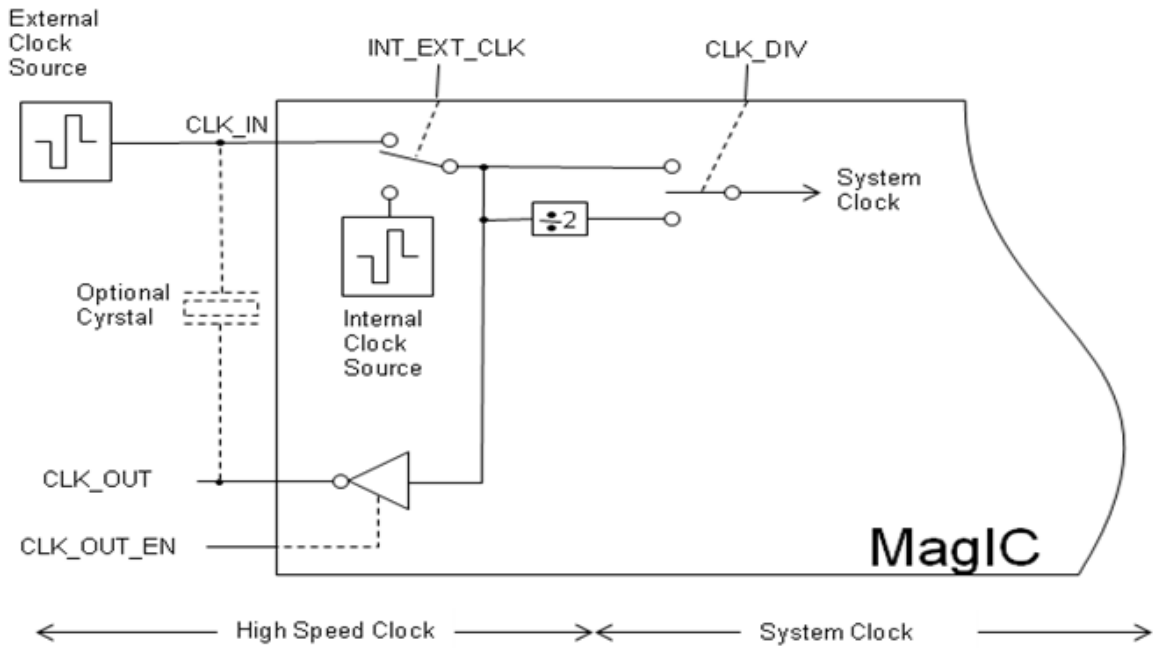

Figure 6-4: Clock Configurations

7 Operation

Data flow to and from the MagIC is through a hardware handshaking, synchronous serial interface that adheres to the SPI bus protocol. Section 6 reviews the various interface lines and provides brief descriptions of some of their functions.

(The MagIC ASIC interface is based on PNI's 11096 ASIC interface except the command is changed from 8 bit to 32 bit. The new command word contains similar sensor axis select bits together with startup and period preset values. The measured result is now extended to signed 20bit value, compared to 16 bit in the PNI's 11096 ASIC.)

7.1 Making a Measurement

The steps to make a sensor measurement are given below, and the sequence and timing are given in Figure 7-1 and Figure 7-2. In general, the user sends a command word (see Section 7.2) to the MagIC through the SPI line specifying the sensor to be measured, the period select, and the startup counter. The MagIC returns the result of a complete forward-reverse measurement of the sensor in a 20-bit 2's complement format (range: -524288 to 524287). Note that only one sensor can be measured at a time.

1. SSNOT is set LOW. (This enables communication with the master device.)
2. RESET pin set HIGH, then LOW. This will reset the MagIC.
3. A command word is clocked into the MagIC on the MOSI line. Once 32 bits have clocked in, the MagIC will execute the command (take a measurement).
4. A measurement consists of forward biasing the sensor and making a period count; then reverse biasing the sensor and counting again; and then taking the difference between the two directions.
5. At the end of the measurement, the DRDY line is set HIGH, indicating data is ready. The data is clocked out on the MISO line with the next 20 clock cycles.

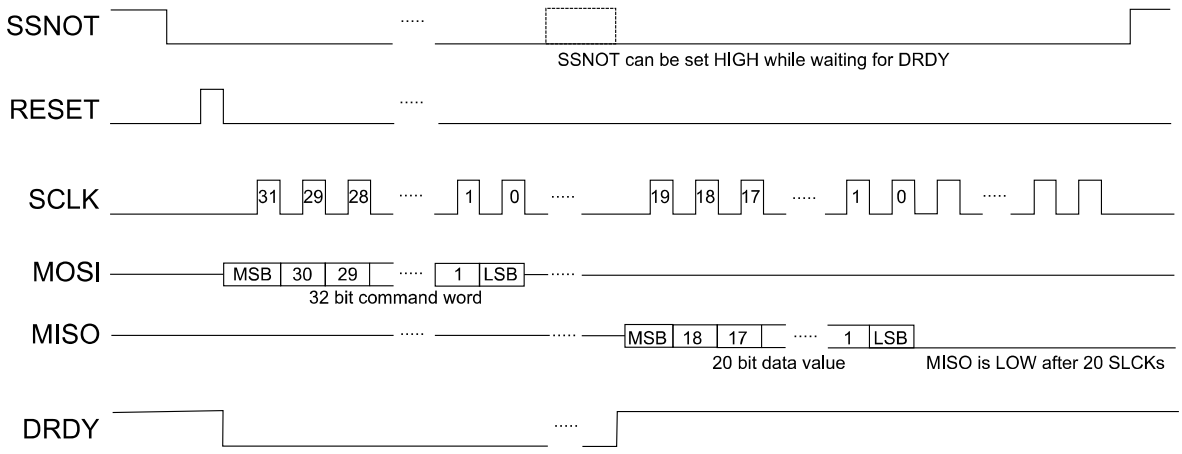

Figure 7-1: Sequence Diagram of SPI Interface

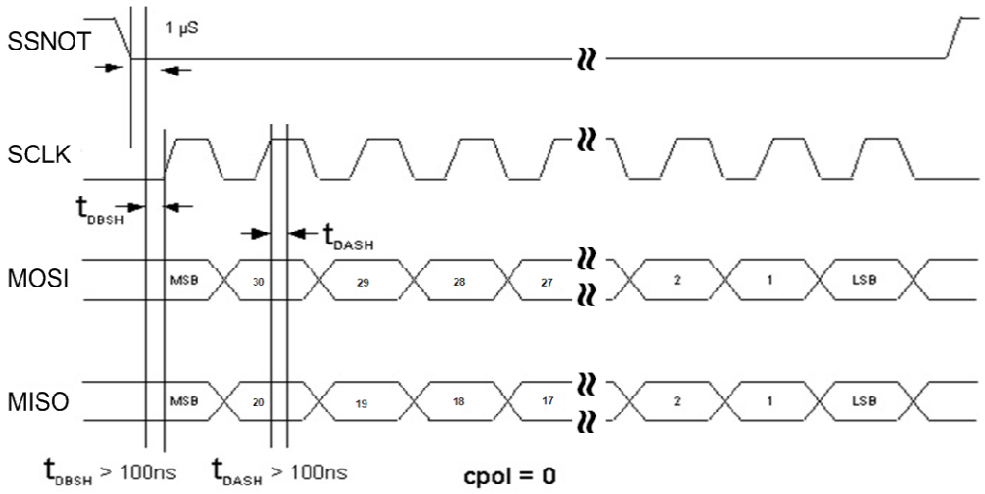

Figure 7-2: SPI Interface Timing

7.1.1 Slave Select (SSNOT)

Keeping the SSNOT line LOW dedicates the master device to the MagIC. If the user has no other slave devices, the SSNOT line can be permanently grounded. Conversely, if the user has multiple slave devices, then the SPI bus can be freed up for other devices by bringing the SSNOT line HIGH. The SSNOT line can be brought HIGH either:

- after sending the command word on the SI line but before reading the measurement data on the MISO line, and/or

- after receiving the measurement data on the MISO line, but before initiating another measurement sequence.

Note: If a new command sequence is started before a previous measurement has been read out, that previous data will be flushed out.

7.1.2 Idle Mode

The MagIC incorporates an idle mode to reduce power consumption, in which it automatically idles when it is not exchanging data or taking a measurement. However, it does not necessarily initialize in the idle mode at power-up. To ensure the MagIC will be in idle mode after being turned on, it is necessary to cycle the MagIC through one measurement request operation. The measurement data does not need to be read out.

7.1.3 SPI Interface Considerations

When implementing an SPI port, whether a dedicated hardware peripheral port or a software-implemented port using general purpose I/O (also known as *Bit-Banging*), the timing parameters (given in Figure 7-2) must be met to ensure reliable communications. When SCLK is LOW, the data is in transition ($\boldsymbol{t}_{DBSH}$ = Time, Data Before SCLK High). The clock set-up and hold times, $\boldsymbol{t}_{DBSH}$ and $\boldsymbol{t}_{DASH}$ must be greater than 100 ns. The clock phase used with the MagIC is zero (CPOL-0). Data is present (MISO) or should be presented (MOSI) before the first low to high clock transition.

Also note that an SPI port can be implemented using different clock polarity options. The clock polarity used with the MicroMagIC must be normally low, (***cpol = 0).*** Data always is considered valid while SCLK is high ($\boldsymbol{t}_{DASH}$ = Time, Data After SCLK High). When SCLK is low, data is in transition ($\boldsymbol{t}_{DBSH}$ = Time, Data Before SCLK High).

7.2 Register Definition

Table 7-1: Command Register

<table>
<tr><th>Bit</th><th>Name</th><th>Description</th></tr>
<tr><td>31:24</td><td>Command</td><td>Command Register. Initiates a sensor measurement
Bits are named as follows:
<table>
<tr><td>31</td><td>30</td><td>29</td><td>28</td><td>27</td><td>26</td><td>25</td><td>24</td></tr>
<tr><td></td><td></td><td></td><td></td><td>ODIR</td><td>MOT</td><td>ASI</td><td>AS0</td></tr>
</table>
ODIR Oscillator Direction
Determines the magnetic oscillator direction if MOT is set to HIGH. If MOT is set LOW, ODIR has no effect. Used for debug only.

MOT Magnetic Oscillator Test
When set HIGH, causes the sensor oscillator selected by AS0 and AS1, in the direction selected by ODIR to run continuously until the Reset pin is set HIGH.

AS0-AS1 Axis Select
Determines sensor to be measured.
<table>
<tr><td>Function</td><td>AS1</td><td>AS0</td></tr>
<tr><td>X</td><td>0</td><td>1</td></tr>
<tr><td>Y</td><td>1</td><td>0</td></tr>
<tr><td>Z</td><td>1</td><td>1</td></tr>
</table>
</td></tr>
<tr><td>23:16</td><td>Startup Counter Preset Value</td><td>5 bit unsigned Startup Counter Preset Value.
(Bit 21 to 23 will be ignored). Default = 0x0F
Configures how many Mag oscillator cycles to count before starting the forward or backward measurement.</td></tr>
<tr><td>15:0</td><td>Period Counter Preset Value</td><td>12 bit unsigned Period Counter Preset Value. (Bit 12 to 15 will be ignored).
Configures how many Mag oscillator cycles to count during a forward or backward measurement.</td></tr>
</table>

Table 7-2: Results Register

Bit	Name	Description
19:0	Measured Sensor Value	Returns measured sensor value in a 20 bit signed value with ranges from -2^{19} to $2^{19}-1$ (2's complement number). Zero's will be returned on MISO if more than 20 SCLK's are sent during a read.

8 Soldering

Table 8-1: Recommended Solder Processing Parameters

Reflow Parameter	Temperature (C)	TIME (sec)
Preheat Temperature (T_{smin} To T_{smax})	150℃ – 200℃	60-180
Temperature T_l (Typical Lead-Free Solder Melting Point)	>218℃	
T_{smax} To T_l Ramp-Up Rate	3℃/Second Max	
Peak Temperature T_p	<260℃	
Time 25℃ To Peak T_p	6 Minute Max	
Time Maintained Above Temperature T_l (T_l)	218℃	60-120
Soak (Time Within 5° Of Actual Peak T_p)		10-20
Rampdown Rate	4℃/Second Max	

a. Meets IPC/JEDEC J-STD-020 profile recommendations

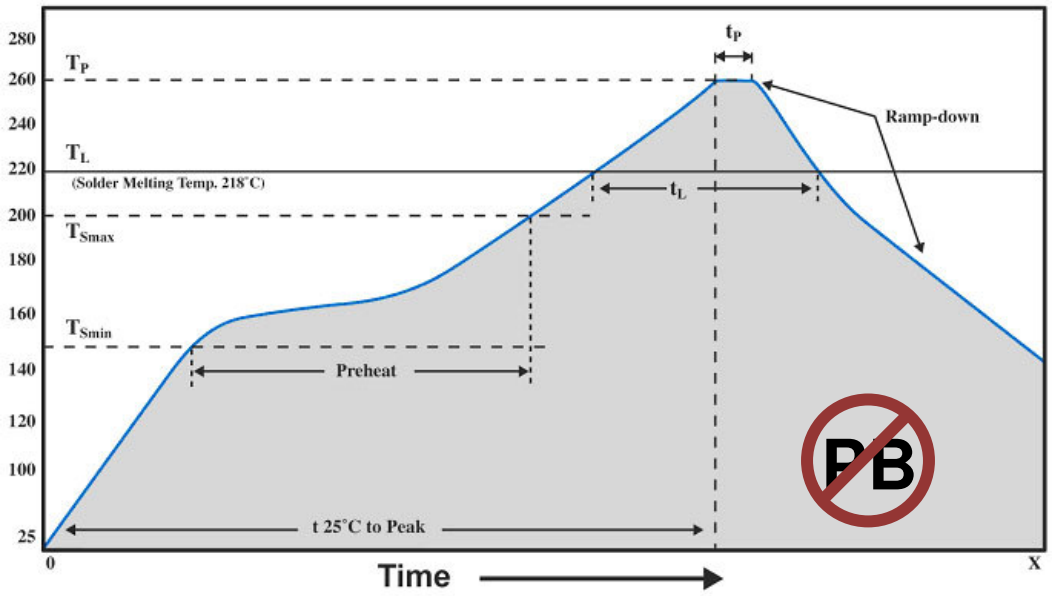

Figure 8-1: Recommended Solder Reflow Profile

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